DOE/ID/13378-T6

**Demonstration of Oxygen-Enriched Air Staging
at Owens-Brockway Glass Containers**

Technical Progress Report for the Period August 1, 1995 - July 31, 1996

By
D. Rue
H. Abbasi

November 1996

Work Performed Under Contract No.: DE-FC07-95ID13378

for
U.S. Department of Energy
Idaho Operations Office
850 Energy Drive, MS 1221
Idaho Falls, Idaho 83401-1563

by
Institute of Gas Technology
1700 S. Mt. Prospect Rd.
Des Plaines, Illinois 60018

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

EXECUTIVE SUMMARY

This report presents the work performed by the Institute of Gas Technology, and subcontractors Combustion Tec, Inc. and Air Products and Chemicals, Inc., during the period from August 1, 1995 through July 31, 1996 under a contract (No.: DE-FC07-95ID13378) with the U.S. Department of Energy, Idaho Operations Office.

IGT, and its commercial partners, have developed a technology, oxygen-enriched air staging (OEAS), which has been shown in tests at three commercial endport furnaces to reduce NO_x levels by 50 to 70%. In this program, the OEAS technology is being extended to the other main type of glass furnace, sideport furnaces.

The OEAS technology utilizes a unique method of combustion air staging to control NO_x formation by reducing the oxygen available in the flame's high temperature zone and improving flame temperature uniformity. The amount of primary combustion air entering through the port(s) is reduced to decrease NO_x formation in the flame, and oxygen-enriched air is injected into the furnace near the exhaust port(s) to complete the combustion in a second stage within the furnace. The OEAS technology has been successfully retrofitted to five endport container glass furnaces, including two commercial sales.

Owens-Brockway, the largest container glass producer in the United States, has joined the team to test the potential of the OEAS technology and has chosen to demonstrate it on its 325-ton/day, Furnace C, in Vernon, California. The field evaluation is the subject of this project.

The OEAS technology addresses glass industry research priority 2.d. in DOE RFP. No. DE-PS07-95ID13346, *Develop improved, cost-effective air emissions systems or optimized furnace designs to meet the more stringent regulations of the future (i.e. removal of NO_x , SO_x and particulates emission). Integrated process improvements are preferred over add-on devices.*

For the successful application of the OEAS technology to sideport furnaces, the key development areas are, 1) to provide good mixing of the secondary oxidant with the primary zone combustion products, and 2) to provide the proper secondary oxidant distribution strategy (equally split between the ports or optimized for each port) to minimize overall NO_x emissions and maximize combustible burnout in the second stage within the furnace, while minimizing oxygen (used to enrich the secondary oxidant) consumption. These key areas can only be addressed through development testing on a representative sideport glass furnace.

The development approach is to 1) acquire baseline operating data on the host sideport furnace in Vernon, California; 2) evaluate secondary oxidant injection strategies based on earlier endport results and through modeling of a single port pair; 3) retrofit and test one port pair (the test furnace contains six port pairs) with a flexible OEAS system; 4) based on the results from testing the one port pair (item 3), design, retrofit, and test OEAS on the entire furnace (six port pairs); and 5) analyze test results, prepare report, and finalize the business plan to commercialize OEAS for sideport furnaces.

During this reporting period, all project work described above was completed up to the implementation of OEAS on the full furnace, full furnace OEAS testing, finalization of the business plan for commercialization, and preparation of the final report. Details of the modeling calculation methodology and results, baseline furnace testing, single port pair implementation, and single port pair results are presented in this report.

The modeling work by Air Products and Chemicals, using a FLUENT CFD approach, provided valuable insights into various staging options. Modeling results concluded that OEAS does not increase crown temperatures. CO emissions were calculated to be effectively reduced with staging with CO emissions decreasing with an increase in jet velocity for the same amount of staging air. Side-of-port staging jets were determined to be incapable of penetrating into the furnace which means all combustible burnout will occur in the exhaust port(s). OEAS arrangements were estimated to not negatively impact furnace thermal efficiency. Furnace thermal efficiencies were not determined to be decreased until the primary stoichiometric ratio is reduced to 0.86. A NO_x reduction of 34% was calculated for side-of-port and two-hole underport injection. Lower NO_x reductions were found for furnace crown and one-hole underport injection. Furnace crown injection was observed to produce secondary oxidant impingement of the glass surface. One-hole underport injection was calculated to cause secondary oxidant-flame interaction and poor port coverage, resulting in higher NO_x and ineffective CO burnout.

The single port testing has shown the best results with OEAS using enriched air with 35% oxygen. Testing demonstrated significant NO_x reduction of up to 35%, effective CO burnout, and no exhaust port temperature increases at preferred OEAS operating conditions. Both two hole underport and side-of-port injection are acceptable OEAS positions. Two-hole underport injection is preferred for several reasons.

Two-hole underport injection produced the same, high levels of NO_x reduction as side-of-port injection while completing combustible burnout and heat recovery inside the furnace. Side-of-port injection provides burnout only in the ports which, while effective, will not recover heat inside the furnace and may result in temperature increases in the port. Furnace crown injection lowers the effective NO_x reduction, possibly by the production of additional NO_x through oxidant-flame contact, and also causes impingement of the secondary oxidant with the glass surface. One-hole underport injection proved incapable of providing effective port coverage which results in incomplete combustible burnout and elevated CO levels in the stack.

The project team evaluated the modeling and single port pair testing results and determined to proceed with two-hole underport injection as the OEAS strategy for the full furnace retrofit. All materials have been procured and/or fabricated. The project team is ready to install the OEAS system on the full furnace and conduct both parametric and long-term testing.

TABLE OF CONTENTS

	<u>Page</u>
Introduction	1
Background	1
Discussion	4
Modeling	4
Baseline Testing	8
Single Port Pair Testing	9
Full Furnace Retrofit	12
Problems Encountered	13
Future Work	14
References	15

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Effect of First Stage Stoichiometric Ratio on NO _x Production	3
2	Oxygen-Enriched Air Staging Concept For a Sideport Furnace	4
3	Material and Energy Streams (Sankey) Diagram for the Side-of-Port OEAS Arrangement	5
4	Modeled Region: Front View. Crown, Underport, and Side-of-Port Injections	6
5	Modeled Region: Top View. Side-of-Port Injections Are Angled Toward the Exhaust Flow	6
6	Staging Combustion With Side-of-Port OEAS	7
7	The Effect of Reduced Stoichiometric Ratio on NO _x	10
8	The Effect of Reduced Stoichiometric Ratio on CO	10
9	Effect of Enriched Air (35%) Staging on NO _x at Port 5	11
10	Effect of Enriched Air (35%) Staging on CO at Port 5	11

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Baseline Furnace Emissions Data	9

Introduction

The objective of the program is to demonstrate the use of a previously developed combustion modification technology to reduce NO_x emissions from sideport regenerative container glass melters. This technology, known as oxygen-enriched air staging (OEAS), has been demonstrated, and is now being commercialized, for endport container glass furnaces. A 17-month development program has been established with specific objectives to: 1) acquire baseline operating data on the host sideport furnace in Vernon, California, 2) evaluate secondary oxidant injection strategies based on earlier endport furnace results and through modeling of a single port pair, 3) retrofit and test one port pair (the test furnace has six port pairs) with a flexible OEAS system, and select the optimal system configuration, 4) use the results from tests with one port pair to design, retrofit, and test OEAS on the entire furnace (six port pairs), and 5) analyze test results, prepare report, and finalize the business plan to commercialize OEAS for sideport furnaces. The host furnace for testing in this program is an Owens-Brockway 6-port pair sideport furnace in Vernon, California producing 325-ton/d of amber container glass. The baseline NO_x level of this optimized furnace is about 4.0 lb/ton of glass. An anticipated NO_x reduction of 50% will lower the NO_x production level to below 2 lb/ton. Secondary oxidant staging techniques being considered include oxygen-enriched ambient air staging (OEAS) and oxygen staging (OS).

The OEAS technology utilizes a unique method of combustion air staging to control NO_x formation by reducing the oxygen available in the flame's high temperature zone and improving flame temperature uniformity and combustion efficiency. The amount of primary combustion air entering through the ports is reduced to decrease NO_x formation in the flame, and oxygen-enriched air is injected into the furnace near the exit port to complete combustion in a second stage within the furnace. The OEAS technology has been successfully retrofitted to three endport container glass melting furnaces; a 150 ton/d endport glass tank producing flint glass in Huntington Park, California, a 200 ton/d endport glass tank producing amber glass in Houston, Texas, and a 320 ton/day endport glass tank producing flint glass in Huntington Park, California. With endport furnace NO_x reduction levels of 50-70%, the OEAS technology shows an excellent potential for similar performance on sideport furnaces. Sideport furnaces are used for nearly 65% of U.S. glass production. Although the potential successful application of OEAS to sideport furnaces is high, considerable design effort and development testing are required. Endport and sideport furnaces are similar in concept, but these furnaces are significantly different in physical design and flame characteristics.

The project team consists of IGT, which originated the concept and is the prime contractor, and the following subcontractors: Combustion Tec, Inc. (CTI), combustion equipment manufacturer and commercialization partner; Air Products and Chemicals, Inc. (APCI), O_2 supplier and commercialization partner; and Owens-Brockway Glass Containers, glass producer, and owner of the host site.

Background

Regenerative glass furnaces use high combustion air temperatures (2200° - 2400°F) to improve productivity, product quality, and furnace thermal efficiency. Flame temperatures are thus quite high as is NO_x production. NO_x emissions over 10 lb/ton glass are common.¹ NO_x emission regulations are in force in Southern California and Europe and mandated or planned for other regions. Current limits in Southern California

are 4 lb/ton for container glass furnaces. There are no current national U.S. NO_x emission regulations, but this could change in response to the 1990 Clean Air Act Amendments.

To address existing and anticipated regulations, the project team has developed a cost-effective, retrofit NO_x control technology for regenerative, natural gas-fired glass melters. This technology, which involves a unique method of air staging, is already commercial for endport glass furnaces, is being demonstrated on a sideport container glass furnace in the present program, and is applicable to many other types of high-temperature material processing furnaces.

Regenerative glass melters generally produce NO_x by thermal processes. Thermal NO_x depends on the time-temperature history of the flame and increases with both increasing flame temperature and oxygen availability in the high-temperature region. NO_x formation can be reduced by either lowering the peak flame temperature or reducing oxygen availability.

Reducing excess air level is the easiest way to reduce oxygen availability. At excess air levels below 25%, NO_x production declines with decreasing excess air even as flame temperature rises. Since glass melters commonly operate with 5 to 15% excess air, lowering excess air will reduce NO_x formation, but, a secondary result is the formation of carbon monoxide. The unique air staging method known as oxygen-enriched air staging (OEAS) allows an endport furnace or many (to all) of the ports of a sideport furnace to operate at a minimum excess air level or even fuel rich.. NO_x formation is kept to a minimum and the combustion process is completed within the furnace using various staging options. Other benefits of reduced air firing include improved heat transfer to the melt resulting from higher flame temperature, greater luminosity, and higher system efficiency resulting from lower excess air discharge.

In the early 1980s, IGT and Combustion Tec developed and tested several NO_x control techniques, including air staging, on an IGT glass tank simulator. Low excess air firing tests were conducted on the glass tank simulator and two commercial glass furnaces. Also, glass tank simulator tests were conducted in which ambient air, as the secondary oxidant, was injected near the exhaust port to maintain an overall stoichiometric ratio of 1.15. A general correlation, shown in Figure 1, was found between the primary stoichiometric ratio and NO_x production. Reducing the PSR from 1.15 to 1.05 reduced NO_x by 35%, and the secondary oxidant effectively burned out CO generated in the primary flame. Additional testing found an added benefit of reducing the PSR is an increase in heat transfer. A significant increase in heat transfer was realized in the IGT glass simulator tests at the reduced PSR.

Figure 1. Effect of First-Stage Stoichiometric Ratio on NO_x Production

OEAS has been installed on five endport container glass furnaces producing amber and flint container glass.² NO_x emissions were decreased from 50 to 73% using several means and types of oxidants including hot air and compressed ambient air for air staging.³ Air staging on these furnaces increased CO at the top of the regenerator, but stack CO levels were unchanged.

For the current sideport installation, the enriched air is supplied to injectors at the ports by air and oxygen skids. This approach was selected as a consequence of the distance between the inlet and the exhaust ports which precludes the use of hot inlet air from the firing side as part of the secondary oxidant. Figure 2 illustrates the sideport furnace air staging configuration. The use of two skids allows any desired level of oxygen enrichment to be used for air staging.

Sideport furnace testing provides the opportunity to examine several secondary oxidant injection locations. Successful secondary oxidant injection must meet the following criteria: complete coverage of the exhaust gas stream, sufficient furnace penetration without impinging on the main (primary) flame and forming additional NO_x, and complete burnout of CO and THC (total hydrocarbons) within the furnace.

Figure 2. Oxygen-Enriched Air Staging Concept For A Sideport Furnace

Discussion

The work in this project can be divided into modeling of a single port pair, baseline testing, single port pair testing, full furnace parametric testing, full furnace long-term testing, the fabrication and installation of the OEAS system, and business plan preparation. The results of the modeling, baseline testing, single port pair testing, and OEAS system fabrication performed to date are presented in this report. The full furnace testing, installation of the full furnace OEAS system, and the business plan will be described in the project Final Technical Report.

Modeling

Prior to the implementation of OEAS on a single port pair of the sideport furnace, several staging options were examined. Variables that had to be considered were the amount of O_2 in the staging oxidant, the velocity of the oxidant, and the location and number of staging jets. Logistically, it was convenient to introduce the staging oxidant through backup oil burner ports from the two sides of the port neck ("side-of-port") because no modification to the melter was required. However, this injection strategy might not achieve effective CO burnout, and the secondary combustion might not take place inside the melter. To gain insight into these issues and, in general, to eliminate a number of the variables prior to field testing, Air Products and Chemicals, Inc. conducted extensive computational modeling.

Material and energy balances were performed at a system level to assess the gross effects of OEAS and particularly, the impact of lowering the primary stoichiometric ratio

(PSR) from 1.1 to 0.95 on overall furnace efficiency. The two regenerators were included in the analysis, as illustrated in Figure 3. Under the new PSR conditions, it was determined that the amount of preheat air through the regenerator decreases while the preheat air temperature increases by approximately 70°F. The analysis further showed that the thermal efficiency of the melter remains the same or improves slightly; however, if the PSR is reduced below 0.86, there will be a penalty to thermal efficiency. At the PSR selected for NO_x reduction, the furnace efficiency is not expected to be negatively affected.

Information from the thermodynamic analysis was used in a detailed computational fluid dynamics (CFD) model of the number 5 port area of the melter. The model incorporates the two-equation $k-\epsilon$ turbulence model of Launder and Spalding.⁴ Radiation heat transfer is computed with the discrete transfer radiation model (DTRM) by Shah.⁵ This model solves the radiative transfer equation directly along discrete rays emanating from all surfaces and is highly desirable for natural gas-air flames due to their relative transparency. A two-step chemical reaction mechanism describes the combustion kinetics and the Magnussen-Hjertager⁶ model takes into account the turbulence-chemistry interactions. All physical properties of the mixture are computed from individual species properties which are functions of temperature as described in the JANAF tables.

Figure 3. Material and Energy Streams (Sankey) Diagram for the Side-of-Port OEAS Arrangement

The governing equations for the conservation of mass, momentum, energy and chemical species are solved with the FLUENT software package.⁷ It uses a control volume based finite difference scheme where nonlinear variations of dependent variables are included inside each control volume to ensure physically realistic results even on

relatively coarse grids. The current CFD model (region of the #5 port pair as shown in Figures 4 and 5) has approximately 62,000 grid control volumes. A nonuniform grid was employed so that regions of high gradients would have denser mesh. It was important, for example, that the staging nozzle regions have enough grid density to ensure accurate predictions of jet penetration and mixing.

Figure 4. Modeled Region: Front View. Crown, Underport and Side-of-Port Injections

Figure 5. Modeled Region: Top View. Side-of-Port Injections Are Angled Toward the Exhaust Flow

The current operating conditions were modeled starting with the baseline case, which established the datum for comparison. Next, OEAS with side-of-port staging injection at three jet velocities was evaluated. The PSR was changed from 1.10 to 0.95 while the overall stoichiometric ratio (OSR) remained at 1.10; oxygen enrichment for the staging injection was set at 35%. The model output revealed that peak temperatures on the melter crown and breastwalls should remain essentially the same while temperature distributions within the port neck through the target wall region would remain within the normal temperature band defined by the reversals of the regenerators. It was also determined that complete CO destruction could be achieved at high jet velocities (approximately 300 ft/s). Relative to the baseline level of 3.7 lb per ton, NO_x formation was predicted to decrease by at least 34%. However, secondary combustion was shown

to occur completely within the exhaust port, as shown in Figure 6. This prediction was consistent with the experimental data of Platten and Keffer⁸ who studied the extent of penetration of jets into a uniform stream at various angles in a low speed wind tunnel under isothermal conditions. For maintained thermal efficiency, it is highly desirable that secondary combustion take place inside the melter. Thus alternate injection strategies needed to be explored.

Figure 6. Staging Combustion With Side-of-Port OEAS

Possible alternate injection locations considered were from the crown and under the port. Crown access is unacceptable to some operators due to safety concerns, however the location was explored as it appeared reasonable that superior staging oxidant coverage of the pre-exhaust port combustion space would be provided. Under-port injection has fewer safety risks but is an intuitively questionable choice since direct opposition to the exhaust flow might again cause jet penetration to be limited. To quantitatively evaluate these options, three models were examined: crown injection with one nozzle, underport injection with one nozzle, and underport injection with two nozzles. The results revealed that while crown injection recovers more than 90% of the energy due to secondary combustion, only about 21% NO_x reduction (as compared to more than 34%) is achieved due possibly to interaction between the staging oxidant and the primary combustion zone. In addition, crown injection intersects the exhaust flow almost perpendicularly, penetrates the combustion gases, and causes flow impingement on the glass bath. Although the single-nozzle underport option does not cause impinging flow to the glass bath, NO_x reduction is similar to that of the crown option. Overall,

underport injection with two nozzles was found to be the best staging option considered. Heat recovery is substantial. NO_x reduction is similar to the side-of-port option. Furthermore, there is no physical influence on the glass bath or impact on the main combustion zone. These findings were corroborated by the testing results.

Baseline Testing

Field testing was conducted on an Owens-Brockway sideport furnace located in Vernon, California. This six port pair furnace produces amber container glass. Two Owens Illinois burners are fired in each port. Firing rates vary with the highest natural gas firing rates in ports 3, 4, and 5 and the lowest firing rates in ports 1 and 6. Overall furnace oxygen to natural gas primary stoichiometric ratio (PSR) could not be directly measured during single port pair testing but was measured during full furnace OEAS demonstration. Metered flows and exit regenerator measurements showed ports 1 and 2 have the highest PSRs and ports 3, 4, and 5 have the lowest PSR values. All ports are operated with a PSR of more than 1.0.

Before conducting staging tests, baseline data were collected for the furnace. Temperatures were measured with type R thermocouples positioned at the port neck of port 5 at the entrance to the regenerator where they were shielded from furnace radiation. Gas samples were obtained with water cooled probes inserted in the back of the regenerators directly in line with the ports. On the left side of the furnace the building wall required the use of 4.5 foot probes which extended 3 feet into the 12 foot wide regenerator. On the right side of the furnace, 6 foot probes extending 4.5 feet into the regenerator were used. Stack samples were obtained through a stainless steel tube. Table 1 shows baseline port and stack measurements made during single port pair testing. Baseline furnace conditions were different during full furnace testing, and NO_x stack emission values varied between 2.3 and 3 lb/ton of glass during the week of OEAS testing. Ports are numbered from the charging end.

The baseline emissions monitoring confirmed a wide variation in port stoichiometries with the highest excess air used in ports 1, 2, and 6. Because the ports are not isolated, port emission levels are affected by mixing in the furnace and by regenerator top crossflow. NO_x decreased with decreasing excess air while showing a trend toward higher levels away from the charging end of the furnace. When the exhaust port O_2 concentration was below 1.5%, incomplete combustion produced a significant amount of CO. Review of the baseline data led to selection of port 5 for air staging evaluation. Port 5 is not at either end of the furnace and has a high firing rate while producing high NO_x with a moderate level of excess O_2 .

Table 1. Baseline Furnace Emissions Data

Sample Location	O ₂ , %	CO, vppm (at 0% O ₂)	NO _x , vppm (at 0% O ₂)	NO _x , lb/ton
Right Side Port 1	5.0	12	980	--
Right Side Port 2	4.5	14	930	--
Right Side Port 3	1.5	90	910	--
Right Side Port 4	2.1	50	980	--
Right Side Port 5	1.9	190	1150	--
Right Side Port 6	3.1	250	1070	--
Left Side Port 1	4.8	11	940	--
Left Side Port 2	4.3	16	930	--
Left Side Port 3	1.5	130	840	--
Left Side Port 4	1.0	1500	880	--
Left Side Port 5	2.3	60	1480	--
Left Side Port 6	3.5	40	1380	--
Stack - Right Side Fire	7.7	10	1220	4.8
Stack - Left Side Fire	7.7	12.8	1340	5.7

In preparation for OEAS testing, CTI installed an oxygen skid with a capacity of 20,000 SCFH and a blower air skid with a capacity of 70,000 SCFH on a platform above the furnace control room. The oxygen skid was connected to the available plant oxygen supply. The skids are sized for full furnace OEAS operation with the capability of feeding air, any level of enriched air, or oxygen as secondary oxidant.

Single Port Pair Testing

Single port pair testing was conducted at port 5. Side-of-port injection through available burner blocks was tested on both sides of the furnace. Furnace crown and underport (with one or two injectors) OEAS injection locations were also evaluated. All injectors were connected to both the oxygen and the air skids.

Primary stoichiometric ratios were lowered without air staging to determine optimum PSR values and potential NO_x reduction levels. A preferred PSR was then selected for OEAS testing. OEAS tests evaluated all staging positions and a number of secondary oxidants.

Figures 7 and 8 show the effects of changing port 5 PSR on NO_x and CO. For both right and left side firing, NO_x levels decreased with reduced PSR. NO_x reductions as high as 35% were reached. CO concentrations increased dramatically with decreasing PSR. At low PSRs, the CO concentration in the regenerator was over 3000 vppm.

Figure 7. The Effect of Reduced Stoichiometric Ratio on NO_x

Figure 8. The Effect of Reduced Stoichiometric Ratio on CO

After baseline testing, a PSR was selected for port 5 which gave a NO_x reduction of 30 to 35%. All single port OEAS testing was conducted at the same port 5 PSR value.

Figures 9 and 10 show the effects of enriched air (35% O₂) staging on NO_x reduction and CO burnout. Figure 9 shows that side-of-port and two-hole underport injection have only a small effect on the NO_x reduction achieved by lowering the primary

stoichiometric ratio. At the same time, Figure 10 shows that CO is effectively burned out with both side-of-port and two-hole underport injection.

Figure 9. Effect of Enriched Air (35%) Staging on NO_x at Port 5

Figure 10. Effect of Enriched Air (35%) Staging on CO at Port 5

The NO_x reduction achieved by lowering PSR was reduced by approximately 50% with both one-hole underport injection and furnace crown injection. These two staging options may generate NO_x when oxidant interacts with the primary flame. The furnace crown position appears to significantly reduce CO from 3000 vppm to under 1000 vppm, but the one-hole underport injection approach produced exhaust gas with 2000 vppm CO which will produce high stack CO levels. This underport position may not provide good port mouth coverage which would allow high CO-content product gases to enter the port.

NO_x levels increased when oxygen was used as the secondary oxidant and high temperature combustion zones were formed. This effect was seen at all staging locations with side-of-port injection producing the smallest increase in NO_x. Staging with highly enriched air (50% O₂ or more) and oxygen caused the exhaust port temperature to increase by 20° to 80°F. This temperature was lower or unchanged when staging with 35% enriched air and air. For the full furnace retrofit, overall PSR will be decreased by lowering total furnace air flow. With OEAS operating along with a lower full furnace PSR, exhaust port temperatures are expected to be equal to or lower than under baseline furnace operating conditions.

Full Furnace Retrofit

Analysis of the single port pair testing showed that two OEAS staging positions: side-of-port and two holes underport, effectively burn out CO while not increasing the overall NO_x level. Staging with enriched air containing 35% O₂ did not increase exhaust port temperatures at either of these positions. Higher oxygen enrichment did result in temperature increases. Evaluation of these two positions revealed significant advantages to the two hole underport position. Therefore, the two hole underport OEAS staging strategy was recommended for the full furnace.

Drawings were prepared by CTI showing the positions of injectors and downcomers for underport and side-of-port injection in the furnace. These drawings were sent to IGT and Owens-Brockway for review.

A decision was made to proceed with the full furnace retrofit using the two hole underport injection location. This decision was reached after review of the single port pair testing and examination of the injector locations. Immediately after this decision was agreed to by Owens-Brockway, CTI, and IGT, fabrication of injectors and other equipment was begun at CTI. Efforts were focused on conducting the full furnace testing on the full furnace during the last week of August.

Personnel changes at CTI have caused a delay of several weeks in the testing schedule for the full furnace retrofit. New testing staff positions will be assigned, and testing was still planned for late in August. Before testing begins, two underport holes will be drilled at each port, and injectors will be installed. Downcomers will be used to connect the injectors to the air and oxygen skids. Testing for the full furnace will begin with parametric evaluation of primary stoichiometric ratios, staging flows, and staging

ports. A preferred operating condition will be selected based on the parametric tests, and then a long term test will be conducted at the preferred staging conditions.

Schedules at the Owens-Brockway field site caused delays of several more weeks in the testing schedule for the full furnace retrofit. Hole drilling, injector installation, and the remaining OEAS system connection will be completed early in August. Testing is planned for late in September. Despite the delays encountered in conducting full furnace OEAS testing, the project team anticipates all project work will be completed within the scheduled project period.

Problems Encountered

There have been no changes in the scope of work or implementation of this project. Several delays at the host site have slowed the project, but these delays have not been a significant problem. The project team expects to complete all contracted work in a timely manner. The objectives of this project remain to demonstrate the OEAS on a commercial sideport container glass furnace and to leave a working OEAS system in place on the furnace to provide reduced NO_x emissions.

Future Work

With completion of the modeling work for a single port pair, the single port pair testing, the determination of the full furnace retrofit configuration, and the fabrication of the equipment for the full furnace installation of OEAS, the project team is ready to implement, operate, and test the OEAS system on the full furnace.

Work to be completed before beginning OEAS testing includes:

- The OEAS injection system downcomers and injectors must be shipped to field site in Vernon, California.
- Two underport holes must be drilled through the touchstone below each port in preparation for installation of the injectors which will be used to add oxygen-enriched air to the exhaust side of the furnace.
- The OEAS system must be installed on the full furnace.
- All piping and control systems on the blower air and oxygen skids must be checked for proper operation and to insure safe, leak-free operation.
- The equipment and instrumentation to be used for full furnace test measurements must be checked.

After the OEAS installation is complete, full furnace, parametric OEAS testing will be conducted. The objective of this testing is to determine the most stable furnace operating conditions which produce low NO_x while providing CO burnout inside the furnace by the OEAS system. Variables to be evaluated during parametric testing will include primary and overall stoichiometric ratios, oxygen concentration in the staging oxygen-enriched air, port biasing for oxidant injection, and various furnace operating

conditions (gas rate, air temperature, cullet fraction in feed, electric boost level, etc.) After completion of the parametric, full furnace OEAS testing, the data will be analyzed in preparation for long-term testing and demonstration.

Two technical papers will be prepared describing the results of this demonstration program. A paper will be prepared and presented at the 57th Conference on Glass Problems in October, 1996 in Columbus, Ohio. The second paper will be presented at the 20th World Gas Conference in June, 1997 in Copenhagen, Denmark. Technical progress will also be described in a presentation to the IGT Sustaining Membership Program at the annual meeting in October.

The OEAS system operation manual will be completed and used to conduct plant training on OEAS system operation and maintenance. Long-term OEAS system testing will be conducted at furnace operating conditions determined to provide low NO_x and good CO burnout. Calculations will be made to determine the cost-benefit relationship between using electric boost and additional gas firing with OEAS. If the economics indicate boost removal is cost-effective, additional long-term testing will be conducted at reduced boost conditions.

At the end of the project, a business plan will be developed for moving the OEAS sideport furnace technology to commercial sales. This plan will be modeled after a plan devised, and now being implemented, for OEAS application to endport furnaces.

References

1. Abbasi, H. A. and Fleming, D. K., "Development of NO_x Control Methods for Glass Melting Furnaces," Final Report GRI-87/0202, Chicago, August 1987.
2. Joshi, M. L. et al., "Regenerative Glass Furnace Operating Parameters for NO_x Reduction." Paper presented at the 8th Annual Glass Technology Seminar, Farmington, PA, September 30, 1993.
3. Joshi, M. L., Wishnick, D. B., Madrazo, F. R., Benz, W. H., Panahi, S. K., Slavejko, A. G., Abbasi, H. A., Grosman, R. E. and Donaldson, "Cost-Effective NO_x Reduction Using Oxygen-Enriched Air Staging on Regenerative Glass Furnaces." Paper presented at the 55th Conference on Glass Problems, November 8-9, 1994, Columbus, OH. Published by American Ceramic Society Westerville, OH.
4. Launder, B.E. and Spalding, D.B. "*Lectures in Mathematical Models of Turbulence*," Imperial College of Science and Technology, London, England, Academic Press, 1972.
5. Shah, N.G. *A New Method of Computation of Radiant Heat Transfer in Combustion Chambers*, Ph.D. Dissertation, Imperial College of Science and Technology, London, England, 1979.
6. Magnussen, B.F. and Hjertager, B.H., "On mathematical models of turbulent combustion with special emphasis on soot formation and combustion," *Proc. 16th Symposium (Int'l.) on Combustion*, Cambridge, MA, August 15-20, 1976.

7. *FLUENT User's Guide*, Version 4.3, Fluent Inc., Lebanon, NH, March, 1995.
8. Platten, J.L. and Keffer, J.F. "Entrainment in deflected axisymmetric jets at various angles to the stream," Technical Publication Series, UTMETP-6808, Department of Mechanical Engineering, University of Toronto, June, 1968.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.